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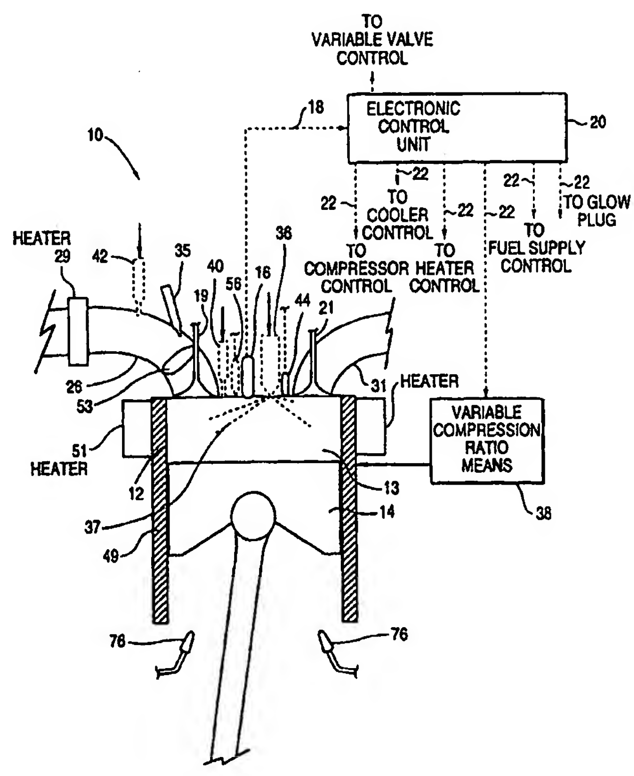
(54) Title: PREMIXED CHARGE COMPRESSION IGNITION ENGINE WITH OPTIMAL COMBUSTION CONTROL

(57) Abstract

A premixed–charge compression–ignition engine and control system (10) is provided which effectively initiates combustion by compression–ignition and maintains stable combustion while achieving extremely low oxides of nitrogen emissions, good overall efficiency and acceptable combustion noise and cylinder pressures. The present engine and control system (10) effectively control the combustion history, that is, the time at which combustion occurs, the rate of combustion, the duration of combustion and/or the completeness of combustion, by controlling the operation of certain control variables providing temperature control, pressure control, control of the mixture's autoignition properties and equivalence ratio control. The combustion control system (10) provide active feedback control of the combustion event and includes a sensor, e.g. pressure sensor (16), for detecting an engine operating condition indicative of the combustion history, e.g. the start of combustion, and generating an associated engine operation condition signal (18).



amount of internal EGR to control the start of combustion (or combustion history) of any or all cylinders.

In order to control the amount of internal EGR, the closing of the exhaust valve or valves is delayed in a variable manner as controlled by, for example, the electronic control module of the engine. A comparison of a normal exhaust event with a "late exhaust valve closing" event is helpful in understanding the present embodiment. In a normal exhaust event, most of the combustion products are expelled during the exhaust stroke. At this point, the exhaust valve closes and the intake valve opens allowing fresh air or an air/fuel mixture to fill most of the combustion chamber as the piston moves downwardly. In the late exhaust valve closing event of the present embodiment, the exhaust valve stays open through part of the intake stroke of the piston. As a result, the engine draws in both fresh air (or mixture) and combustion products. By varying the delay of closing, the amount of internal EGR can be adjusted. Additional internal EGR could be achieved by delaying the opening of the intake valve. The advantage of the present embodiment over early exhaust valve closing is that early exhaust valve closing results in very poor PMEP, while Applicants' studies indicate the late exhaust valve closing does not significantly affect PMEP.

Another advantage of the late exhaust valve closing of the present embodiment is that the exhaust valve need not be closed very quickly. That is, the exhaust valve must only be kept open for a longer period of time. Referring to Figs. 65a-65d, the method of the present invention is illustrated and explained as follows. At the beginning of the exhaust stroke of the piston 500, an exhaust valve 502 is open while an intake valve 504 is closed. As shown in Fig. 65b, at the top dead center position of the exhaust stroke of piston 500, both exhaust and intake valves 502, 504, respectively, are open. As piston 500 begins to move downwardly through the intake stroke as shown in Fig. 65c, a fresh charge of intake air (or fuel/air mixture) is drawn into the combustion chamber through the opening of intake valve 504 while combustion

octane number, to permit the SOC to be effectively controlled by varying the amount of oil or ozone added to the mixture. Also, by using the engine's lubricating oil supply, or using ozone created by the engine during operation, an additional supply of fuel/additive can be avoided.

Equivalence Ratio

Another control variable that applicants have shown can be effectively used to control the SOC and combustion duration or heat release rate is the equivalence ratio ϕ of the fuel/air mixture. Equivalence ratio is equal to fuel/air ratio divided by stoichiometric fuel/air ratio (if $\phi < 1$, fuel deficient; if $\phi > 1$, fuel excess). Combustion needs to be slowed down in a PCCI engine because fast combustion leads to high noise, lowered efficiency and high peak cylinder pressure. If different temperatures and/or equivalence ratios can be achieved throughout the charge of air/fuel at or near point of ignition, the resulting rate of combustion will possibly be slowed down thus advantageously lengthening the duration of combustion. The equivalence ratio could be increased by increasing the fuel flow to the cylinder without a corresponding increase in intake air flow, or by decreasing the intake air flow. The equivalence ratio could be lowered by decreasing the fuel flow to the cylinder without a corresponding decrease in air flow, or increasing the air flow rate. Variations in the quantity of fuel delivered to a cylinder is varied by controlling the operation of fuel control valves 39, 41, and/or fuel injectors 35, 36 in a known manner. The variations in the air flow rate could be achieved by, for example, variably controlling compressor 24 to vary boost pressure.

To test the lower limit for equivalence ratio, applicants conducted engine studies to determine whether acceptable PCCI combustion could be obtained with an extremely lean mixture. The results indicate that very stable combustion can be achieved at an